Metal-Supported Ceria Electrolyte-based SOFC Stack for Scalable, Low-Cost, High-Efficiency and Robust Stationary Power Systems – DoE Kick Off Meeting

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Agenda

Wednesday 16th November

- 10:00 to 10:15 Introductions
- 10:15 to 11:15 Technical Kickoff Presentation
- 11:15 to 11:30 Q&A and Follow Up Discussion

Objectives

- Development of:
    - Complete internal fuel reforming capability
    - Larger active cell area to achieve integrated, compact, low cost 5kW stack
    - Integrated 5 kW modular stack platform scalable from 5 – 100kW
    - 5 kW FCPS demonstrator utilizing integrated 5 kW modular stack platform.
- Demonstration of:
    - 5kW FCPS performance through minimum of 1,000 hours of real-time testing:
        - Galvanostatic Degradation: <0.5%/1000hrs
        - Robustness: >10 on/off cycles; >5 emergency stops (e-stops)
- Cost modelling to show system cost of $1,500/kW (2011 currency basis) achievable at production volumes
- Predictive modelling using demonstration test results to show system lifetime robustness capability of:
    - Galvanostatic Degradation: <0.1%/1,000hrs
    - Robustness: >2,000 on/off cycles ; >60 e-stops

Partners

- Cummins Power Generation

  Is a world leader in the design and manufacture of power generation equipment, with extensive experience in engineering and manufacturing robust and cost effective power generation products against customer requirements. Cummins has a long history working with fuel cell developers of both SOFC and PEM based technologies.

- Ceres Power

  Was founded in 2001, formed out of Imperial College London. Over the past 15 years, Ceres has established itself as the leading metal-supported SOFC supplier, with annual output of approximately 15,000 cells per year. Ceres has partnered with global OEMs including Honda, Cummins Power Generation, KD Navien, and British Gas, for a wide range of power applications

- PNNL

  Has extensive experience in the design, fabrication, and testing of SOFC materials, components, and systems, as documented in over 150 peer-reviewed technical papers and numerous patents. PNNL began developing SOFC technology in 1987, and has played a key role in numerous DOE Programs.

- The University of Connecticut

  Has extensive experience and facilities for testing SOFC stacks, assessing the impact of impurities and evaluation of getter materials for SOFC system integration. UConn will provide the host site for the final demonstration of the program’s 5 kW SOFC system

Work Packages

- 1.0 Project Management, Planning & Control
- 2.0 Technology R&D
  - IP Management
  - Internal Reforming
  - Anode Poisoning Robustness
  - Cathode Poisoning Robustness
  - Larger Area Cell
- 3.0 Requirements and System Engineering
  - Requirements and Specification
  - System Architecture / Design
  - Control System Development
  - Design Robustness
- 4.0 Component Design, Development & Verification
  - Fuel cell Stack
  - Fuel Cell Module
  - Fuel Cell Power System
  - Fuel Cell Power System Test Bay
- 5.0 Fuel Cell Power System Build & Verification
  - Test Bay Procurement and Installation
  - Fuel cell Power System Build
  - Fuel Cell Power System Verification Testing
- 6.0 Demonstration System Testing
  - Install Fuel Cell Power System and Test Stand
  - Run 5kW Fuel Cell Power System Demonstration

Technical Review – Internal Reforming

Ceres' anode technology has been demonstrated at a lab scale to perform high levels of internal methane reforming. Initial testing and simulation shows internal reforming enables increased fuel utilization and reduced air cooling resulting in a potential net efficiency of >60%. This task will advance the maturity of IR technologies.

This task includes the following activities:

- Verification of internal reforming performance, cost & quality (at material, cell, stack and system level)
- Manufacturing process: design, testing and integration to production line with demonstration at MRL 4/5
- Compete IR Stack design, with integration of pre-reformer function into stack
- Compete IR FCM
  - system design
  - prototype build, verification testing / characterisation

The project deliverable for this task is: 1) Design Study: Internal Reforming (document).

Technical Review – Larger Cell Area

The purpose of this task is to develop the technology required to enable an integrated 5kW stack through the development of a cell with a larger active area, scaled up by up to 5 times from Ceres' current cell area for their 1kW system. The following key activities are planned:

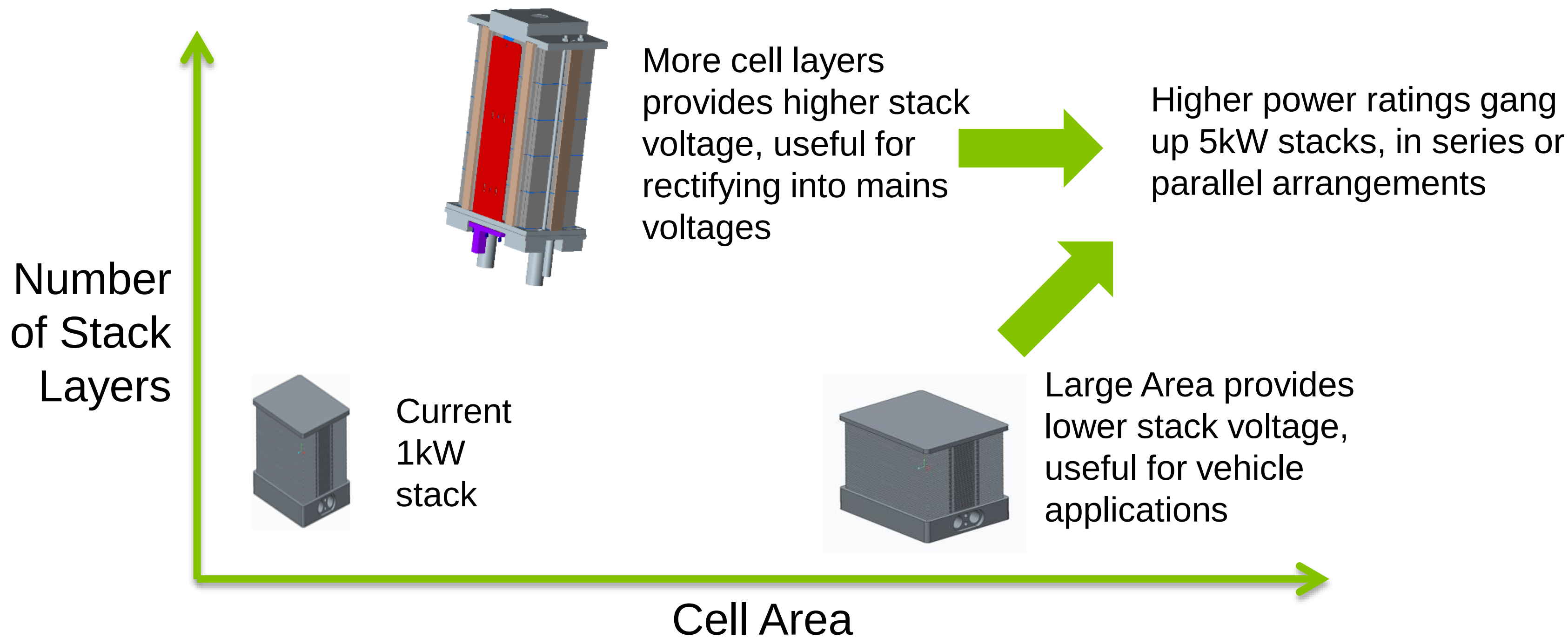
- Assessment of VOC work to right-size cell area and deliver customer requirements
- Explore the art of the possible for larger area cells. Initial manufacturing trials of larger area cells and subsequent analysis of electrode and electrolyte layers to assess condition of microstructure, identify key challenges and opportunities for larger footprint cells
- Analysis of stresses due to sintering of large cells
- Large footprint interconnect design study, including interconnect forming trials
- Stack assembly trials
- Design Internal Reformer function into the cell / stack
- Perform large footprint short stack tests to prove 5kW feasibility (2~4 stacks)
- Develop multi-physics, CFD and FEA models at cell and stack level, validated with 5kW testing
- Develop initial guidelines for large cell designs – incorporating learning from Manufacturing Study, short stack tests, and modelling outcomes

Deliverables for this task include: 1) Larger Area Tall Stack Prototype (hardware), and 2) Larger Area Tall Stack Test Report (document), which together form the deliverables for Milestone #3.

Technical Review – Modular Approach

Advancement of 5kW stack Technology

- Current 5kW stack module is 4 x 1kW stacks
- Various cell area arrangements are possible for a single 5kW stack
- VOC work will impact final approach
  - Possible trade-off between cell area, electrical configuration and stack voltage
- Assessment of cell area and stack modular approach for higher output systems (10-100kW)



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Technical Review – Demonstration Unit

5kW Fuel Cell Power System (FCPS) design and build

- **VOC and product requirements will drive system design**
- **Leading edge technologies required for some systems**
  - Power electronics
  - AOG recirculation
- **Evolution of systems from current FCPS**
  - Thermal integration and management
  - Delivery systems (Air, fuel and water)
  - System controller, software and actuators
- **FCPS functional shakedown at Ceres Power**
- **Demonstration test at UConn in Summer 2018**
  - Galvanostatic Degradation: <0.5%/1000hrs
  - Robustness: >10 on/off cycles; >5 emergency stops (e-stops)

Technical Review – UConn

UConn will be providing Ceres with their latest cathode poison getter material prototypes (developed under the DOE) for designing a stack/ system robust to cathode poisons for US applications.

UConn has been developing different materials as getters for the cathode air poisons with very encouraging results. To date, these materials have been tested at higher temperatures (700+°C), and hence a first step will be to evaluate the proprietary getter material in the Ceres range of operation of 600 – 630°C.

Ceres will be working with U Conn to demonstrate the robustness of short stacks and systems to cathode poisons, with a focus on SO_2 and Cr, with poison getter integrated in the stack design.

Deliverables for this task include: 1) Cathode Poison Getter Prototype (hardware), and 2) Cathode Poisoning Robustness Study (document).

Technical Review – PNNL

Previous studies at PNNL and elsewhere have documented the fact that poisons in fuel gas can have an adverse effect on the performance of nickel-based anodes in solid oxide fuel cells. In this task, PNNL will quantitatively assess the effects of poisons and other contaminants on the performance of anodes in Ceres fuel cells.

- Tests will be performed at PNNL on button cells provided by Ceres Power.
- Cells will be tested using both contaminant-free and contaminant-containing fuel.
- Determination of the effects of the presence of contaminants on cell performance.
- Evaluation of reversibility of observed effects of contaminants on cell performance
- Post-test characterization (e.g., SEM, EDS, and/or TEM) to determine any chemical or microstructural changes in the anodes.

The results of the contaminant tests will provide guidance concerning both short term and long-term effects of contaminants in the fuel on cell performance.

The deliverable for this task is: 1) Anode Poisoning Robustness Study (document).

Technical Review – Cost Modelling

Cost modelling to show system cost of $1,500/kW (2011 currency basis) achievable at production volumes

- **Analysis will be based on DoE guidelines**
- **Cost prediction for increasing production volumes and market applications**
- **Assessment of cost down and production method opportunities possible with higher volumes**

Next Steps

- Voice of Customer – using this data to right size cell area
- Requirements capture leading to system design targets
- Anode and Cathode poison studies commenced